Designing for Network-Centric Warfare

Jeffrey P. Keehn, Aristides Staikos and Gerald T. Michael

As DOD transforms to a network-centric architecture, effective management of increasing bandwidth demands become a more critical element for its success. This article describes a design process that is being pursued to ensure the network has sufficient bandwidth to support successful network-centric warfare implementation.

The Space and Technology Communications Directorate's Multifunctional On-the-move Secure Adaptive Integrated Communications Advanced Technology Demonstration (ATD) included mobility protocols that allow warfighters to transparently join or leave sub-networks in an efficient and timely manner using routing protocols that select the best route/network to use when multiple routes are available, a critical capability for maneuver units. Here, Soldiers from the 1st Squadron, 4th Cavalry Regiment, 1st Infantry Division, move their M1A2 Abrams Main Battle Tank into position during *Operation Iraqi Freedom*. (U.S. Army photo by PVT Brandi Marshall.)

Prior to 1992, exchanges between computers in the tactical environment were performed manually via swivel chair or sneaker net. In 1992, the Army fielded the first tactical packet network as part of Mobile Subscriber Equipment (MSE) for brigade and above command posts, which opened the door for direct Internet-like exchanges between weapon systems. Over the next decade, we saw advances in computer technology and extension of the tactical Internet down to the company level and individual platforms, such as command vehicles and tanks.

MSE has been the Army's communications workhorse for nearly two decades and provided brigade and higher-level command posts with tactical packet networking. But given today's diverse, dynamic and highly mobile battlefield, the Army's demands for increased bandwidth have multiplied exponentially. (U.S. Army photo.)

Combatant commanders quickly recognized that digital exchanges between computer-based weapon systems provided our warfighters a distinct advantage over enemy forces. This transition was the start of network-centric warfare. As more sophisticated systems emerged, the need to transport large volumes of information increased. In parallel, battles were being fought more dynamically, with far greater mobility and over much larger battlefield areas.

It has been stated that there will never be enough bandwidth to satisfy all the unconstrained users' desires. However, with a methodical approach and strategic management oversight, we can use the available bandwidth to provide our commanders a network that will still give them a decisive advantage in battle. The science and technology (S&T) community is taking a three-pronged approach to address the bandwidth issue. Specifically these areas are:

- Communications System Improvements. Focus on improving communications systems individually to increase throughput capacity.
- Bandwidth Management Mechanisms. Focus on developing network mechanisms, such as quality of service (QoS) and access controls, which will allow the network to more efficiently use the available bandwidth.
- Application/System Network Integration. This most important prong is engineering the efficient integration of the applications/systems onto the network.

The combination of these three thrust areas will lead to a system-of-systems (SoS) network that will optimize bandwidth usage and ensure that critical information arrives at its final destination in actionable time.

First, we must ask, "What is enough bandwidth?" It can be defined as the amount of bandwidth necessary to support the information flow that provides the commander decisive battlefield advantage. In a fully integrated SoS that shares information dynamically in real time, optimum individual system performance is not as important as those systems working effectively and efficiently together. The next step is to determine what level of throughput is sufficient, whereby "sufficient" is defined as an appropriate amount of information dissemination that leads to a decisive battle command advantage. Because of the many variables associated with this complex problem, the most cost-effective, practical way one will be able to determine what is sufficient is through extensive modeling and simulation (M&S), supplemented with small-scale experiments and exercises.

Communications System Improvements

The thrust of this prong is to obtain greater throughput out of our communication systems. Enhancements are being pursued for each component of the transmission and switching systems, from the waveform and protocols to the antennas. As a result of fewer available frequencies and congestion in the lower bands, there has been a move to develop systems that operate at higher frequency. Higher frequency provides greater bandwidth but at the expense of less robust propagation characteristics. Military satellite systems are migrating to Ku/Ka and extra high-frequency bands with consideration for laser communications for various applications.

Waveforms have been making steady advances to provide more bits per hertz, therefore providing more data to be packaged in a given frequency. Turbo coding and Orthogonal Frequency Division Multiplexing are two examples. The Defense Advanced Research

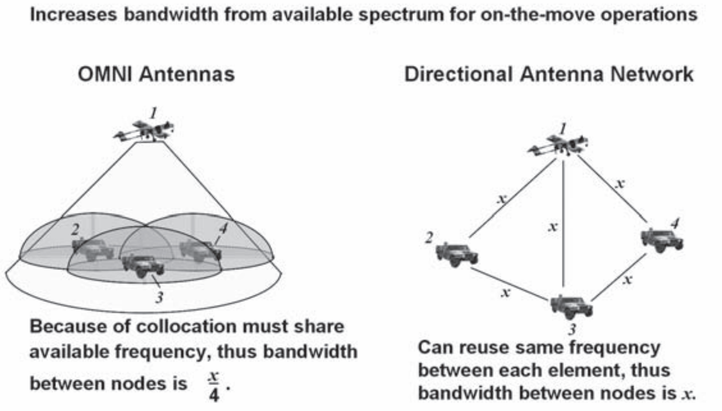


Figure 1. Directional Antenna Networking

Projects Agency and the Army are developing frequency agile waveforms that will allow the radios to monitor the local spectrum and automatically operate in the unused frequencies.

Directional networking antenna employment provides another area where considerable increases can be achieved in throughput within a given area and frequency. As depicted in Figure 1, by reusing the frequencies we can increase the throughput by 2-4 times.

Bandwidth Management Mechanisms

Bandwidth Management Mechanisms are defined as the protocols that will seamlessly bind the sub-networks — such as satellite, Joint Tactical Radio System, Soldier Radio Waveform, Wideband Networking Waveform and Warfighter Information Network-Tactical — into a coherent overall network that will control information flow. Present tactical wireless networks lack appropriate control mechanisms such that as the load on the network increases, network performance degrades rapidly. What makes these control mechanisms challenging is that they need to be designed for use in low-bandwidth, mobile wireless networks where most paths encompass multiple hops that are constantly moving and reorganizing.

However, QoS protocols designed for this mobile wireless heterogeneous environment have major technology challenges in controlling and efficiently using the precious bandwidth in these networks. QoS, in layman's terms, is about "guaranteeing" network performance to ensure higher priority traffic is handled in an appropriate manner.

The Space and Technology Communications Directorate's (S&TCD's) Multifunctional On-the-move Secure Adaptive Integrated Communications Advanced Technology Demonstration (ATD) took a first step in developing QoS protocols for the networking and link layers that work over mobile, multihop heterogeneous networks. Results demonstrated an improvement from 6.0 to 0.95 seconds for latency, and packet completion increase from 40 percent to more than 90 percent in a small multihop network for high-priority traffic. In this case, the best effort traffic suffered so that the higher priority traffic gets the network services it requires. Also included are mobility protocols that allow the warfighter to transparently join and leave subnetworks in an efficient and timely manner, and routing protocols that select the best route/network to use when more than one route is available. S&T programs are addressing these bandwidth requirements as well as providing the commanders management tools to change and optimize the network to match the battle tempo, such as shifting priority from video in the planning stage, to voice and data in the execution phase, to support calls for fire and battle command.

Application and System Network Integration

The most important piece of the process is to design the applications and systems to more efficiently use the network. This design approach requires a teaming effort between the systems and applications engineers and the network designers to be successful. It is critical that these groups meet during the early design phases to ensure the design incorporates and satisfies the requirements and constraints of each other's programs. A team effort using the various techniques shown in Figure 2 and others will bring the applications and systems needs closer to the available bandwidth.

A key driver is to identify and prioritize each piece of transported information within each application or system so that the network can handle it appropriately. It is important to note that all traffic cannot be treated as high priority. If that were the case, networks would revert back to "best-effort" service, which quickly degrades as network loading

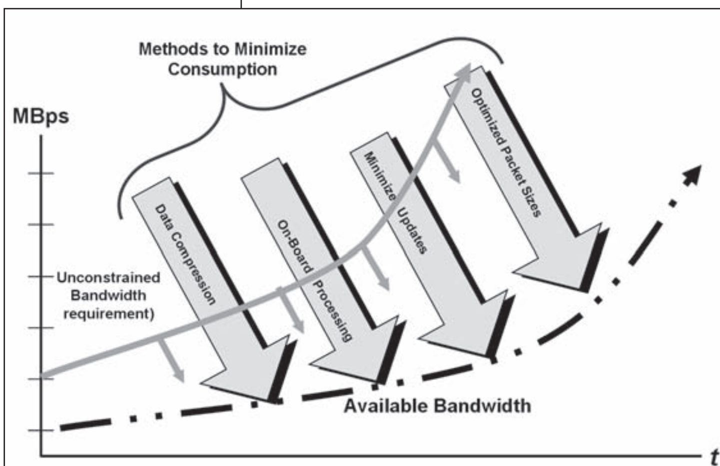
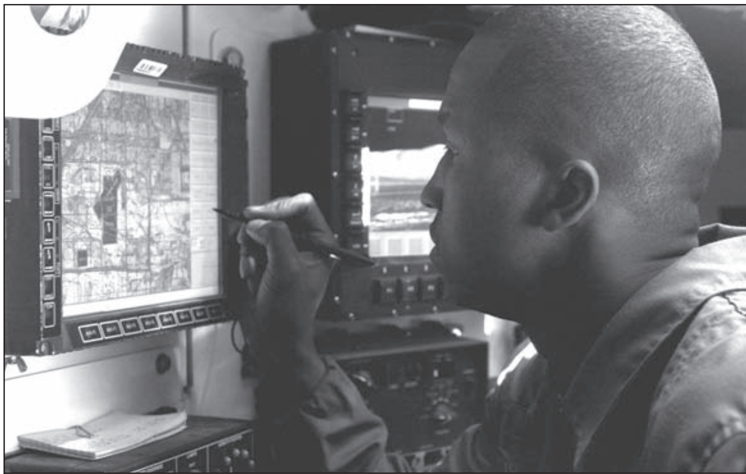


Figure 2. Consumption Mitigation



SFC Kenneth R. Dawson checks the map on his Force XXI Battle Command Brigade and Below display during a live-fire training exercise at the National Training Center, Fort Irwin, CA. Present tactical wireless networks experience degraded network performance as network demands increase. CERDEC has developed an adaptive application middleware that will dynamically control what the application offers to the network based on the network's health at any given point in time. (U.S. Army photo by CPT Tim Beninato, 28th Public Affairs Detachment.)

increases. The network also requires an understanding of other performance metrics associated with varying traffic and application types. Some messages require speed of service, such as "call for fire," while voice calls and video are sensitive to jitter. Other types of applications require zero packet loss such as intelligence imagery to remain effective. The M&S sensitivity analysis addressed earlier is a tremendous tool in determining appropriate priority and other governing attributes for each piece of information.

The U.S. Army Communications-Electronics Reserve, Development and Engineering Center (CERDEC) Command and Control Directorate, under the Agile Commander ATD, developed an adaptive application middleware that dynamically controls what the application offers to the network based on the network's health. Their approach adjusts the contents of a video application's transmission as the network load increases by using various techniques that include compression, reduced frames per second and conversion to black and white.

Another design decision for the application or system user is whether or not to send information via Transmission Control Protocol (TCP) or User Datagram Protocol (UDP). TCP provides mechanisms for "assured delivery," however, at the expense of increased overhead. UDP, on the other hand, doesn't carry the overhead burden, but UDP also does not provide ensured delivery. As the network becomes increasingly congested, message completion falls rapidly.

There are, however, various techniques that exist and are being developed to allow you to transport messages using UDP with the reliability attributes of TCP. Intelligent employment of multicast and anycast transmissions, in place of broadcast, will also contribute to reducing the network's overall load. Another consideration is to adjust update frequency for items such as situational awareness. Great strides have been made in compressing multimedia traffic, including video, voice, data (header and payload) and imagery. Greater collaboration is required between the network and applications and systems engineers to take advantage of these capabilities.

The research and development community has many emerging and promising technologies that will result in greater, more efficient bandwidth utilization. However, these advances will be in vain if the systems and applications are not engineered and designed to take advantage of them. This includes prioritizing each piece of information that the application or system transmits and considering the transport constraints, such as latency and fidelity, associated with each. If a concerted effort is applied to the aforementioned three-prong approach described herein, achieving sufficient bandwidth to make network-centric warfare a reality is possible for the Future Force.

JEFFREY P. KEEHN is CERDEC's Chief of the Special Project Office for S&TCD, U.S. Army Research, Development and Engineering Command (RDECOM). He has a B.S. in mechanical engineering from Villanova University and an M.S. in management science from Fairleigh Dickerson University. Keehn is an Army Acquisition Corps member who is Level III certified in both program management and systems planning, research, development and engineering (SPRDE). Additionally, he is a graduate of the Defense Systems Management College Advanced Program Management Course.

ARISTIDES STAIKOS is an Electronics Engineer for CERDEC's S&TCD at Fort Monmouth, NJ. He has a B.E. in computer engineering from Stevens Institute of Technology and an M.S. in electrical engineering from the New Jersey Institute of Technology. Staikos' publications include "HoneyWEB: Embedded Web-based Control Applications" for the 1999 IEEE Real Time Systems Symposium held in Phoenix, AZ, and a paper written for the *Science and Technology Newsletter* titled "Advanced Protocols for the Future Dynamic, Mobile Battlefield." He is Level III certified in SPRDE and Level I in program management.

GERALD T. MICHAEL is a Senior Engineer in the Systems Engineering, Architecture, M&S Division of CERDEC's S&TCD, RDECOM. He has a B.S. in civil engineering from the Massachusetts Institute of Technology (MIT), an M.S. in civil engineering from MIT and an M.S. in electrical engineering from the Naval Postgraduate School. He is Level III certified in SPRDE.